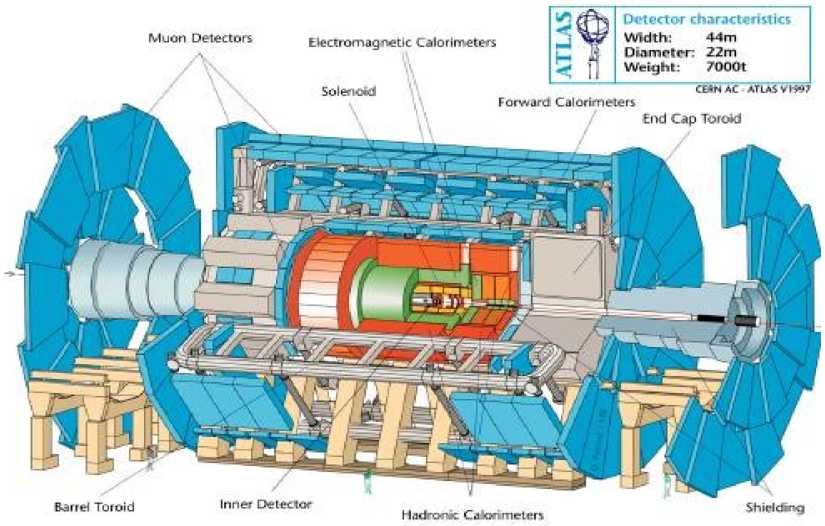
DRD CALO (aka DRD6)
IFIC

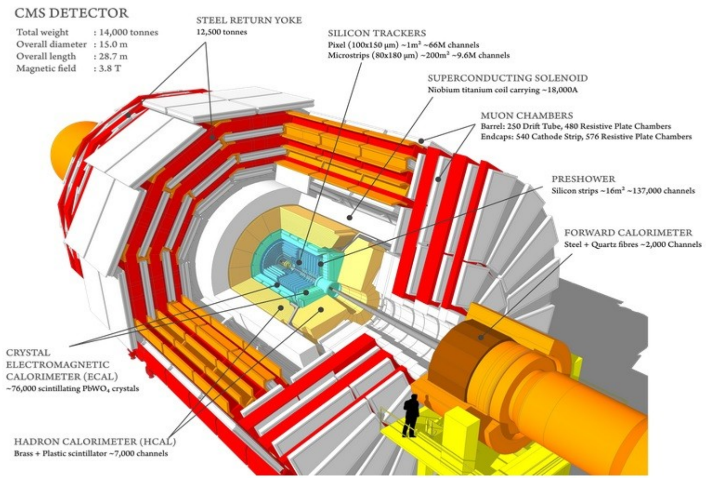
Adrián Irles on behalf the DRD Calo IFIC
IFIC, CSIC-UV

Intro

LHC pp General Purpose detectors

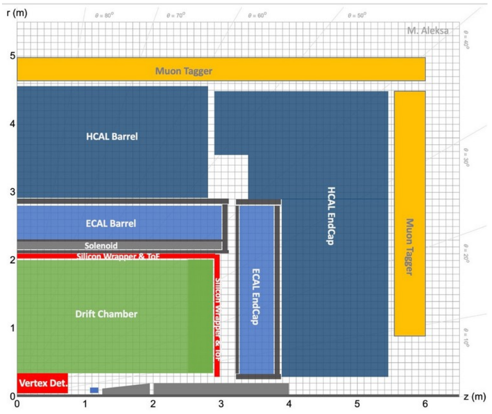


A **Toroidal** Large ApparatuS

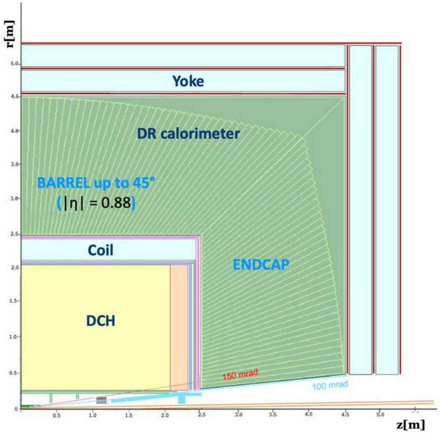


Compact Muon **Solenoid**

Calos: drivers of new detector design for Higgs Factories (few examples)

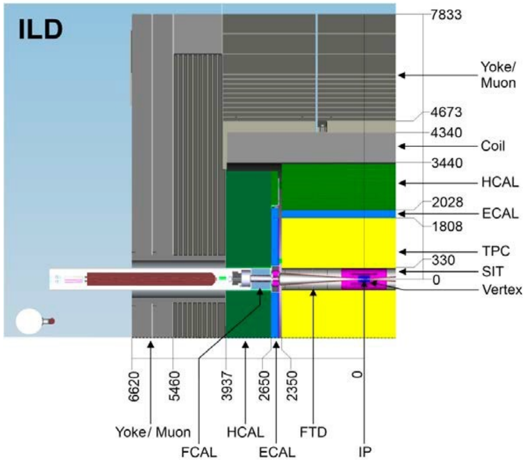


ALLEGRO:
A Lepton Lepton collider Experiment with **Granular** Read-Out
(built "around" a LAr calo)



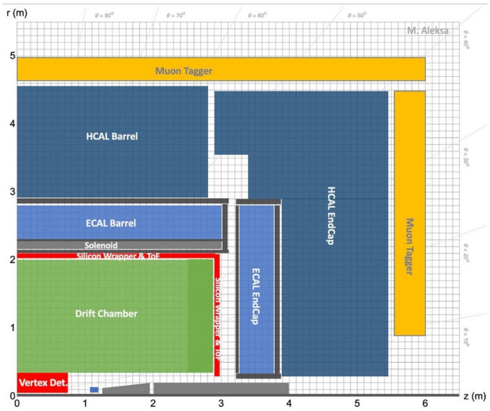
IDEA:
Innovative Detector for E+e− Accelerator
(built "around" a Dual Readout calorimeter)

ILD:
International Large Detector (a Particle Flow Calorimetry detector)



**CLD, SiD, ClicD, CEPC Baseline, etc were born all as modifications/evolutions of ILD*

Calos: drivers of new detector design for Higgs Factories
(few examples)



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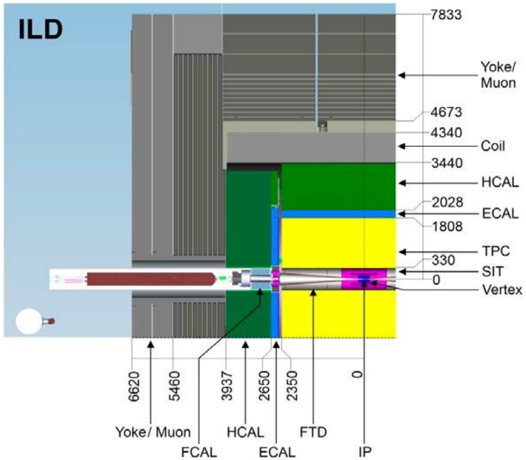
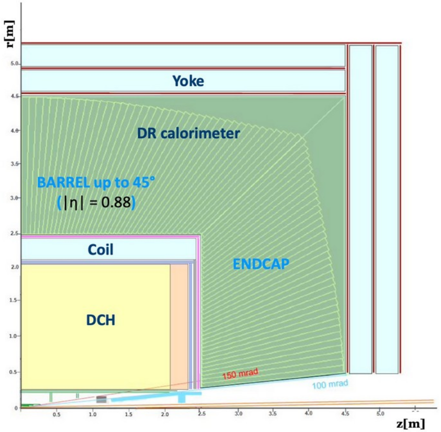




IDEA:
Innovative Detector for E+e− Accelerator
(built “around” a Dual
Readou

all embracing the
high granular calorimetry
Concept at different levels…

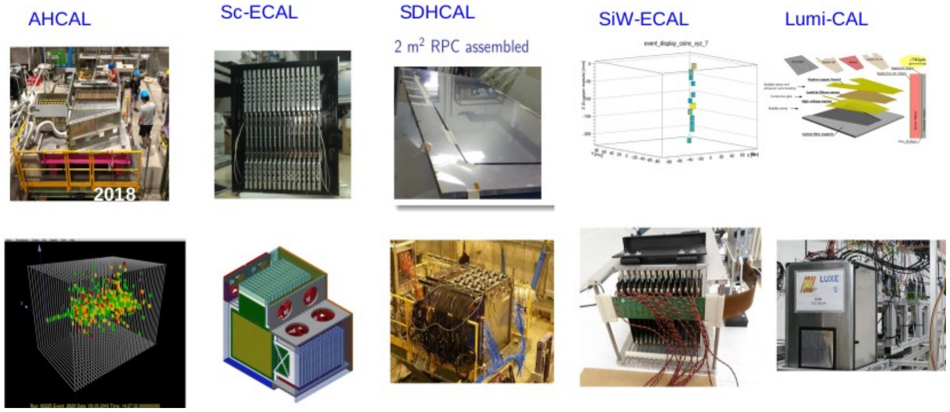
drdcalo

EXCELENCIA SEVERO OCHOA
INSTITUT DE FÍSICA CORPUSCULAR IFIC
VNIVERSITAT DE VALÈNCIA
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

9th March 2026

High Granularity Calorimetry concept

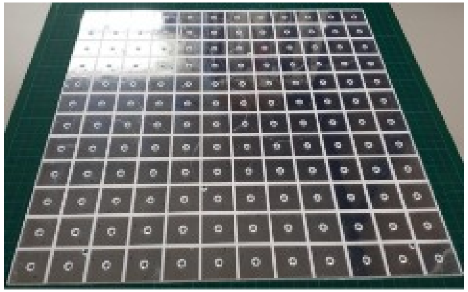
- **R&D and proof of concept initiated by the CALICE and FCAL collaborations, now a larger community within DRD6**



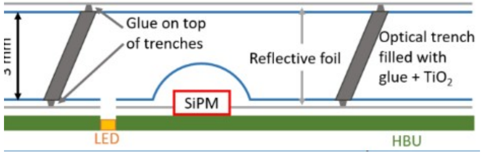
- **Exported to HL-LHC** Upgrade of existing detectors (ALICE FoCAL pixel calorimeter, HGCAL with high granular Si and SC calorimeter systems)
- **Adapted to lower energy** experiments
  - Strong-Field QED experiments (LUXE)
  - Dark Photon, ALPs Experiments (LUXE-NPOD, EBES -KEK, Lohengrin - Bonn,...)

High Granular detectors

Sc Tiles



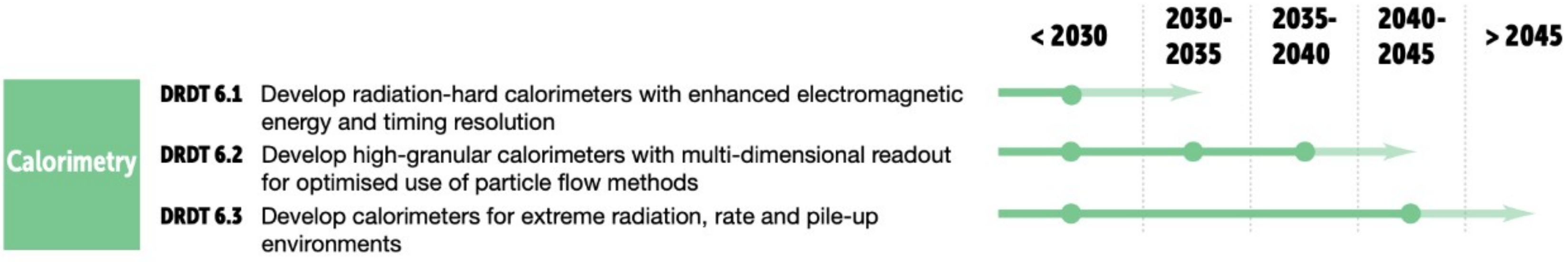
Highly integrated (very) front end Electronics and RO



Achieved milestones in the past: FCAL, CALICE (and CALICE+CMS) beam tests campaign of large size prototypes

DRD Calo & IFIC

DRD Calo



Pre-DRD6 collaborations:
CALICE, FCAL, CrystalClear

DRD Calo

- Definition/creation of the collaboration and interim management during first year by **Proposal team**
  - IFIC participation in the Proposal team (A. Irles)

Proposal Team

Coordinators: Roberto Ferrari, Gabriella Gaudio (INFN-Pavia), R.P. (IJCLab)

Representative from ECFA Detector R&D Roadmap Coordination Team: Felix Sefkow (DESY)

WP 1: Sandwich calorimeters with fully embedded Electronics – Main and forward calorimeters
Conveners: Adrian Irles (IFIC, adrian.irles@ific.uv.es), Frank Simon (KIT, frank.simon@kit.edu), Jim Brau (University of Oregon, jimbrau@uoregon.edu), Wataru Ootani (University of Tokyo, wataru@icepp.s.u-tokyo.ac.jp), Imad Laktineh (I2PI, imad.laktineh@in2p3.fr), Lucia Masetti (masetti@physik.uni-mainz.de)

WP 2: Liquified Noble Gas Calorimeters
Conveners: Martin Aleksa (CERN, martin.aleksa@cern.ch), Nicolas Morange (IJCLab, nicolas.morange@ijclab.in2p3.fr), Marc-Andre Pleier (mpleier@bnl.gov)

WP 3: Optical calorimeters: Scintillating based sampling and homogenous calorimeters
Conveners: Etiennette Auffray (CERN, etiennette.auffray@cern.ch), Macro Lucchini (University and INFN Milano-Bicocca, marco.toliman.lucchini@cern.ch), Philipp Roloff (CERN, philipp.roloff@cern.ch), Sarah Eno (University of Maryland, eno@umd.edu), Hwidong Yoo (Yonsei University, hdyoo@cern.ch)

WP 4: Electronics and DAQ
Christophe de la Taille (OMEGA, taille@in2p3.fr)

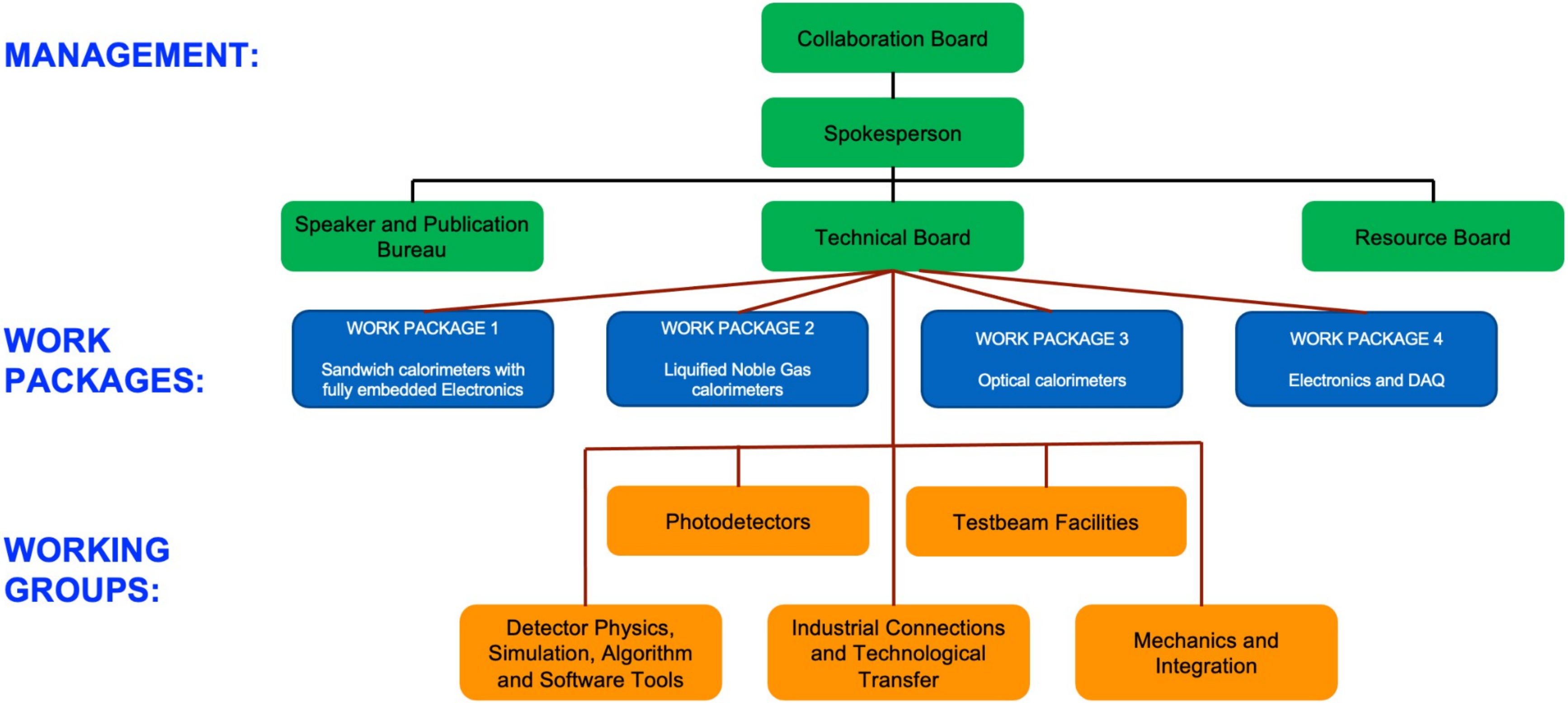
Transversal Activitiies
Photodetectors: Alberto Gola (FBK, gola@fbk.eu)

Collaboration Meeting – April 2024

https://cds.cern.ch/record/2886494/files/DRD6-cdscern.pdf

DRD Calo

▷ As of September 2025, the DRD Calo consists of 134 institutes from 27 countries.



https://drdcalo.web.cern.ch/

drdcalo

DRD Calo

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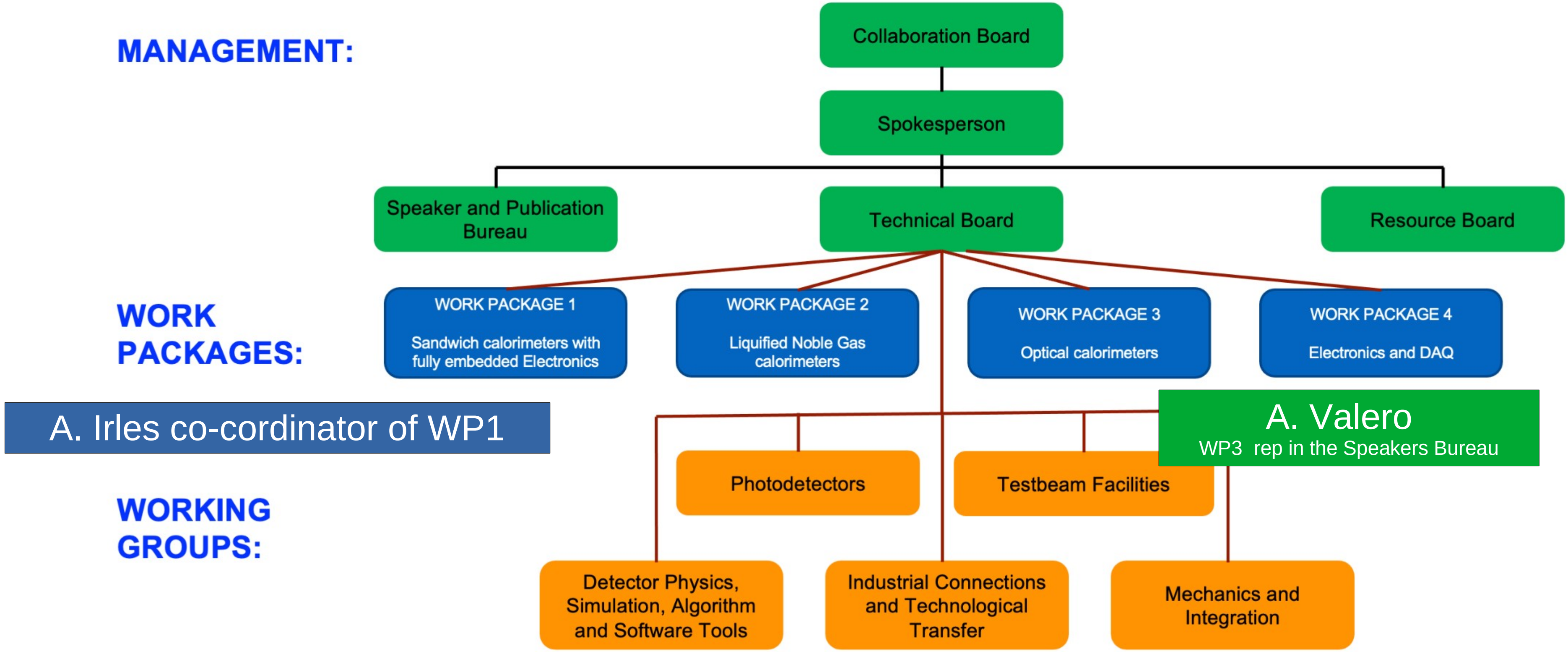


https://drdcalo.web.cern.ch/

WP1 Sandwich calorimeters with fully embedded electronics

▷ **General approach:**

- Highly granular calorimeters as integrated systems - but often still with separate requirements and correspondingly separate technological solutions for electromagnetic and hadronic sections.

▷ **Overarching goals:**

- Establish (where not existing already) large-scale prototypes that allow to demonstrate the technologies, both stand-alone and in combined tests of different electromagnetic and hadronic sections.

▷ **High-level structure**: Tasks covering technology areas

- Task 1.1: Highly pixelised electromagnetic section **– SiECALs**
- Task 1.2: Hadronic section with optical tiles
- Task 1.3: Hadronic section with gaseous readout

WP3 Optical Calorimeters

▷ **General approach:**

- Development of calorimeters based on optical detection of scintillation and Cherenkov light, including both homogeneous and sampling calorimeter concepts. Emphasis on exploiting advanced scintillating materials and compact photodetectors (e.g. SiPMs).

▷ **Overarching goals:**

- Explore, optimise and demonstrate novel optical calorimetry concepts through prototypes with full shower containment, advancing their technological readiness for future collider experiments.

▷ **High-level structure**: Tasks covering technology areas

- Task 3.1: Homogeneous and quasi-homogeneous electromagnetic calorimeters (crystal-based)
- Task 3.2: Innovative sampling electromagnetic calorimeters **- PicoCAL**
- Task 3.3: Hadronic sampling calorimeters with optical readout **- TileCAL**
- Task 3.4: Scintillating materials and optical media for calorimetry

DRD Calo Spain

DRD Calo IFIC groups

▷ **IFIC – Team Leaders (Gray Book) A. Irles & L. Fiorini**:

- WP1 SiWECAL (ILD/CLD) & Luminometers (all detectors)
- WP3 TileCal (HL-LHC ATLAS & Allegro for Allegro)
- WP3 PicoCAL (HL-LHC LHCb)

DRD Calo other spanish groups

▷ **CIEMAT -**
- Mary Cruz – SDHCAL and TSDHCAL (WP1)

▷ **DIPC Donostia**
- Roberto Soleti - CRILIN (WP3)

▷ **UB-ICCUB:**
- Eduardo Picatoste – SpaCAL (WP3)

▷ **UCO** (Córdoba)
- José Berenguer T-SDHCAL (WP1)

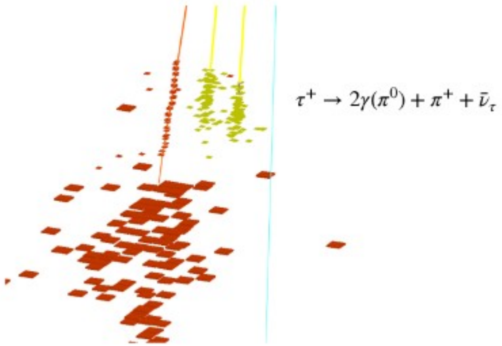
▷ **UVO** (Oviedo)
- Pietro Vischia - Software

1st DRD CALO Spain Meeting @ IFIC, January 2026
https://indico.ific.uv.es/event/8313

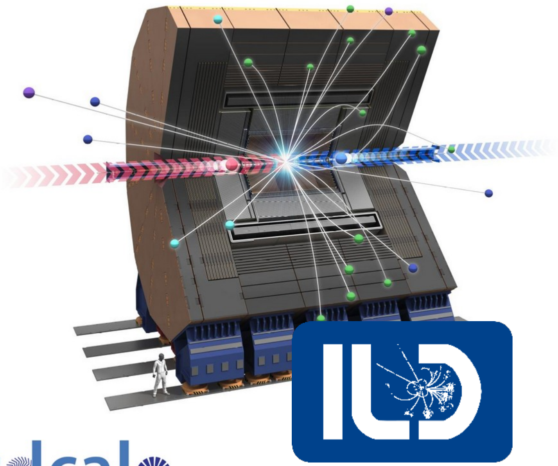
Activities

- Summary talks during the 1st DRDCalo Spain Meeting
- WP1 - SiECALs
  - A. Irles https://indico.ific.uv.es/event/8313/contributions/29441/attachments/14723/21490/Silicon_ECALs_IFIC.pdf
- WP3 – TileCAL
  - A. Ruiz https://indico.ific.uv.es/event/8313/contributions/29442/attachments/14727/21489/ARuiz_DRDCalo2026.pdf
- WP3 – PicoCAL/LHCb
  - E. Picatoste (UB) https://indico.ific.uv.es/event/8313/contributions/29443/attachments/14731/21491/DRD_Spain_-_UB-UPC-IFIC_PicoCal_20260113.pdf

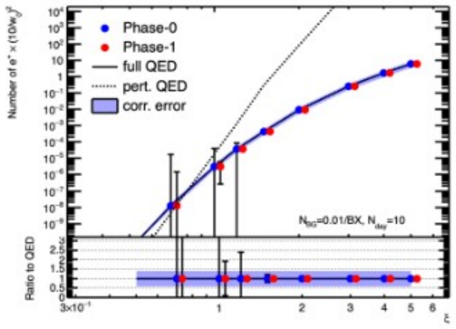
WP1@IFIC - Si ECALS



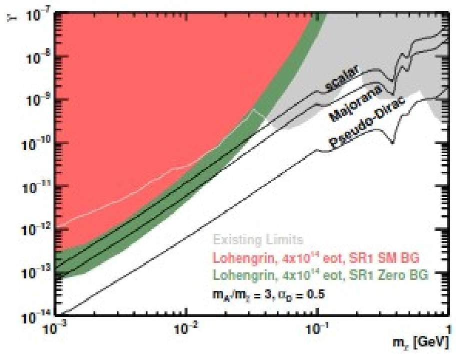
- Results in close-by / overlapping electromagnetic and hadronic showers



- **Silicon Electromagnetic Calorimeters** is one of the **most** robust and **advanced concepts**, optimal for Flavour physics, Higgs/EW physics, QED (luminosity)
- **ECAL** barrel proposals
  - *Optimal for Particle Flow Higgs Physics and High Precision Flavor Physics*
  - *refs ILD for ILC ILD for FCC and LC SiW-ECAL for FCCee (Higgs)*
- *Si-ECAL for **Luminometers***
  - *Crucial for all physics program – speciall the EW physics program of FCC*
  - *Si-ECAL for FCCee (lumi)*
- Prototypes are **also adapted for Strong-FieldQED** and direct **Dark Matter** experiments (LUXE, LUXE-NPOD, Lohengrin, ShiP, EBBES)



LUXE and LUXE-NPOD
https://arxiv.org/pdf/2308.00515



Lohengrin https://arxiv.org/pdf/2410.10956

drdcalo

WP1@IFIC - Si ECALS

TARDIS-Lab

Controlled access clean Room with HEPA filters.

Qualified as **ISO7**.

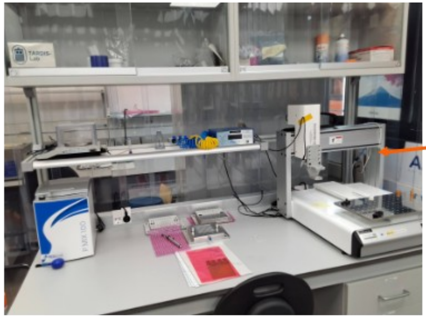
Compatible with **ISO5** with in-situ measurements of particles bellow 1um

https://agenda.linearcollider.org/event/10594/contributions/57544/

The **TARDIS-Lab** is a new installation at IFIC devoted to **characterization** and **hybridization** of **silicon sensors** for **high granularity calorimetry**.

It is a **unique facility** in Europe, key in the R&D programs of the **DRD-Calo** and **FCAL collaborations.**

- ✓ Key installation for DRD Calo WP1
- ✓ Prototypes for ECAL barrel and Luminometers in construction at IFIC
- ✓ Stepping stone before any Higgs Factories: LUXE/ShiP/...

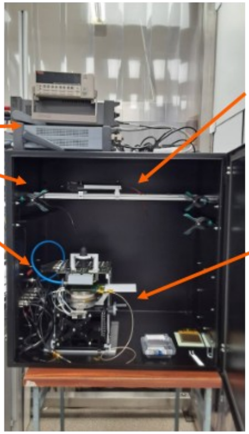


Programmable 3D robot (PDS-400-3) for positioning and control of volumetric deposition (PreciFluid). Planetary Mixer and degassing P.MIX100

Usual epoxy-silver glues: epotek H20E, MGChem 9410

Work area and control PC: probe-station; PDS-400-3, readout modules for sensor commissioning.

Slow control monitoring (humidity, temperature)

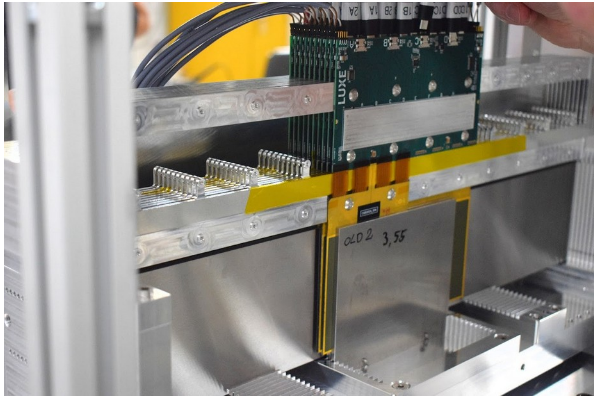


Single module set-up with radiactive sources (Sr90 8kBq) and cosmic rays

Probe-station with dedicated electronics to characterize **CALICE-Hamamatsu sensors with IV/CV**

- ARRAY HGC Sensor - Switching matrix
- CALICE 6-inc Probe Card
- Keithley 6487
- Keysight E4980A/AL
- Keithley 2470

Nozzles for N_2 injection.
WIP: temperature control

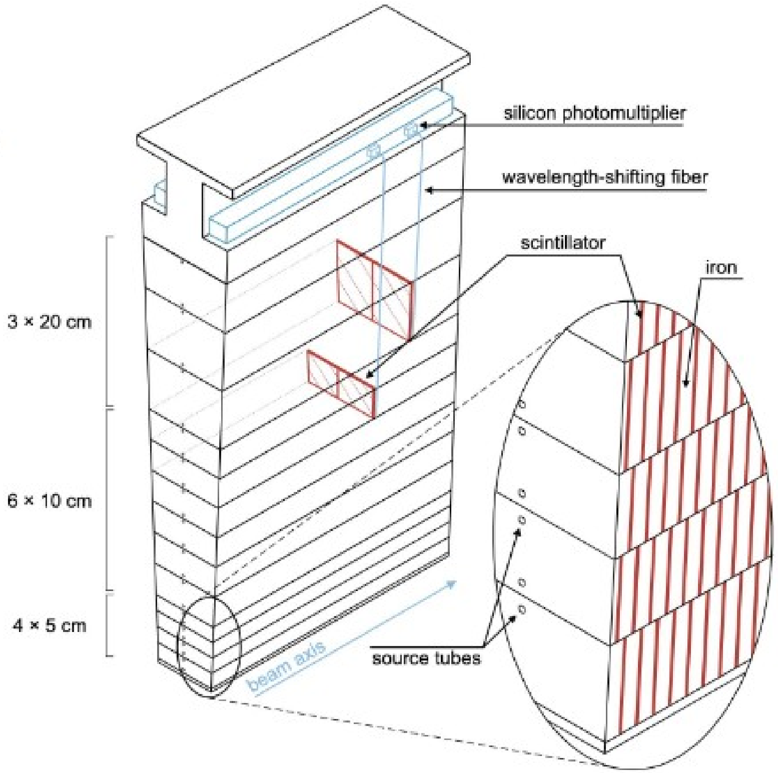


Testbeam campaings: 2025 DESY
2026 CERN

Its external dimensions are: 3,0 x 2,5 x 2,7m³
Its internal dimensions are unknown but it was established that it is bigger in the inside.

WP3@IFIC – TileCAL for ALLEGRO

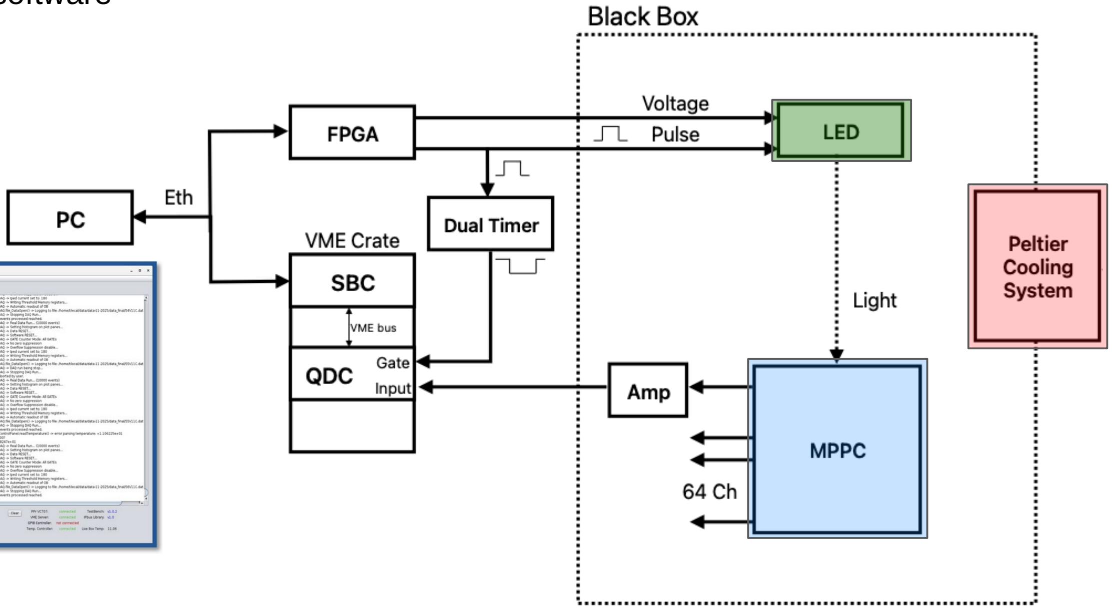
- ALLEGRO: detector proposal for FCCee
  - Calorimeter similar to ATLAS (EM + Had) with enhanced segmentation
- Well established participation of group in ALLEGRO
  - Increasingly mature proposal of a TileCal-like HCAL
  - Greater longitudinal and transverse segmentation → Improved spatial resolution
- Current TileCal-like design in simulation:
  - 5 mm steel absorber plates alternating with 3 mm scintillator plates
  - 128 modules in φ, 2 tile/module → Δφ = 0.025
  - 13 radial layers (4 x 5 cm, 6 x 10 cm, 3 x 20 cm)

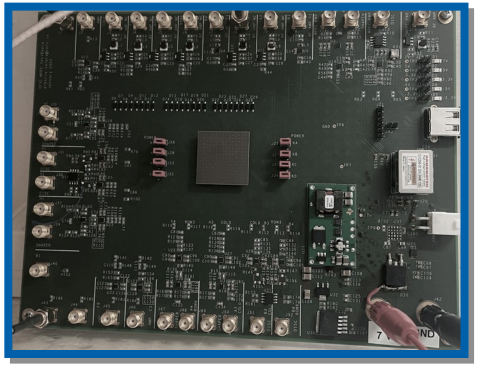


Participation in the first ALLEGRO TileCal testbeam at CERN's SPS in May

Setup at IFIC TileCal Lab

- **Black box** + **Peltier** for temperature control
- **Multi-Pixel Photon Counter (MPPC)** coupled to interface board
- Light source: **LED** (470 nm wavelength)
- 32-channel QDC for signal read-out
- Modules for trigger and DAQ
- Custom DAQ software

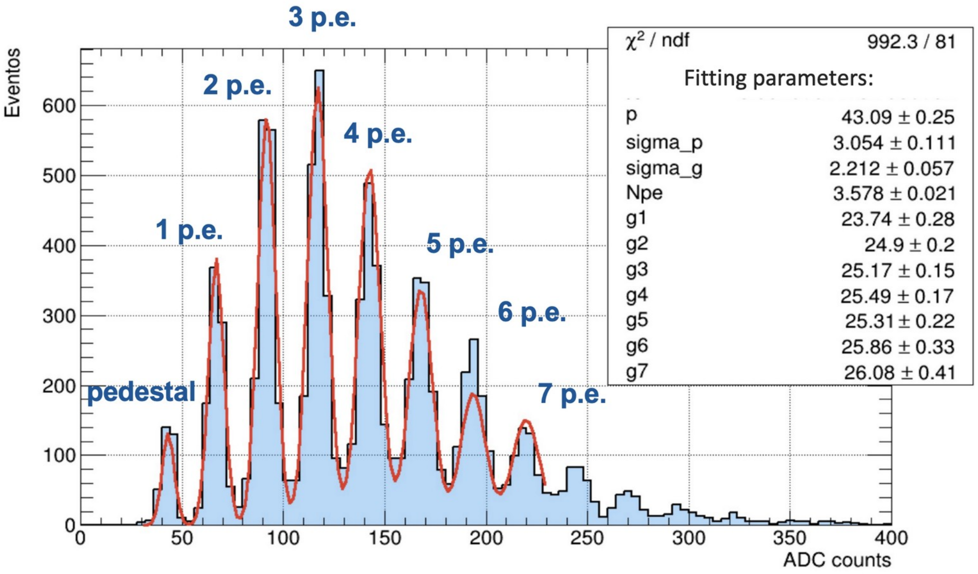


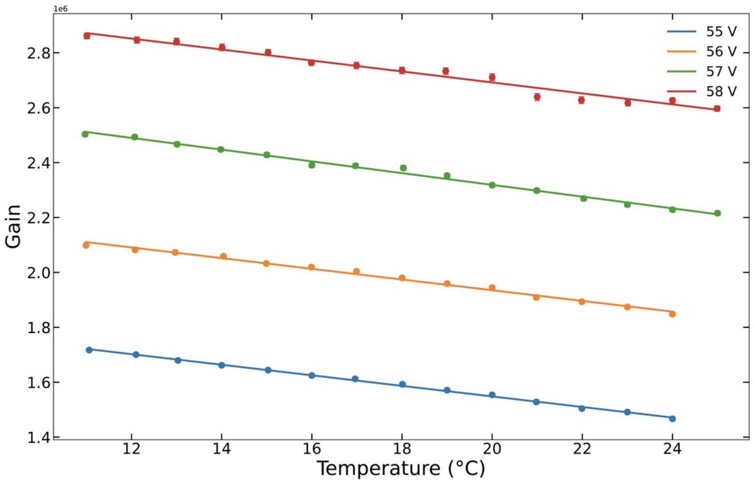


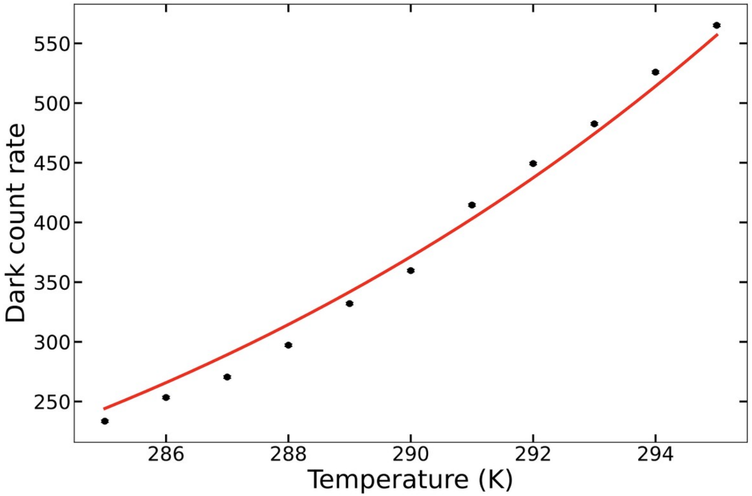
- Setup update replacing LED source with Laser + Integrating sphere → Fully characterize several MPPC models

Characterization of MPPCs

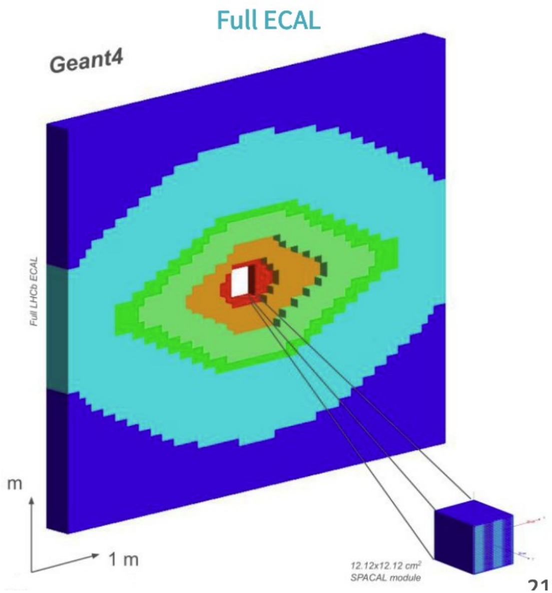
- Discerning single photoelectrons → Pulse height spectra fitted to a **sum of Gaussians convoluted with Poissonians**
- **Mean gain vs. temperature:** linear decrease and good agreement with Hamamatsu specifications
- Also measured **dark count rate** (pulses from thermally generated carriers in absence of photons)

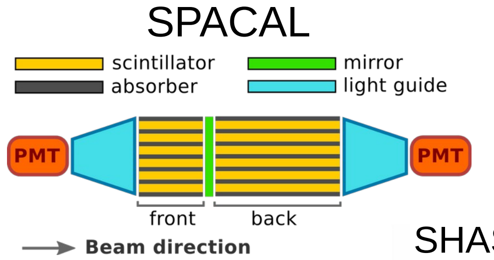


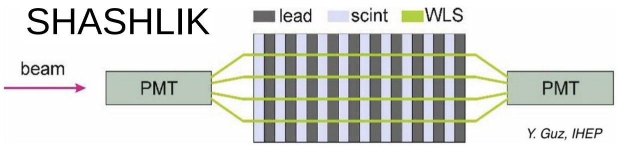




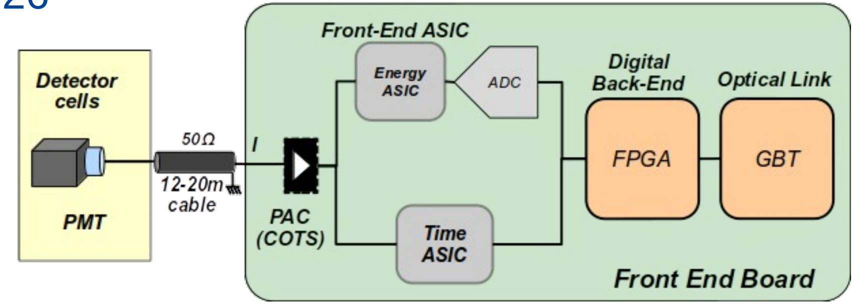
WP3@IFIC PicoCal for LHCb Upgrade II







- Rad-tolerant calorimetry system with timing capabilities
  - Energy resolution of $\sigma(E) / E \approx 10\% / \sqrt{E} \oplus 1\%$ up to 40GeV E_T
  - Time resolution O(10ps) up to 5GeV E_T
- Heterogeneous module design with double readout
  - SpaCal (W and Pb) and Shashlik (Pb) absorber configurations
  - GAGG crystals and Polystyrene fibers/tiles scintillators
  - cell size ranging from 1.5x1.5cm^2 (red) to 12x12cm^2 (indigo)
- MCD-PMT readout with two dedicated ASICs
  - ICECAL65: pulse shaping integrator with internal digitization
  - SPIDER: configurable analog-sampling waveform digitizer TDC
- TDR planned for Q4/2026
- Spanish contributions readout development (IFIC, UB, UPC)



9th March 2026

Summary - DRD Calo works on R&D for Calorimetric systems

- Focus on **Higgs Factories** detector concepts – special emphasis on high granularity
  - But also on near-future smaller experiments.
- WP1 – SiliconECAL
  - In synergy with **CALICE** (absorbed by DRD Calo) and **FCAL R&D collaborations**.
  - **Goals**: Higgs Factory and LUXE & small experiments
  - **Funding**: CIDEGENT/2020/021 Estudios de física e I+D en detectores para futuros colisionadores de leptones ; PID2024-158190NB-C21 Avanzando la física de altas energias: experimentos en colisionadores e I+D tecnologico *(+ASFAE/PID2021/CIPROM2021..., finalized)*
- WP3 – TileCAL
  - Synergies with **DRD7** (electronics)
  - **Goals**:: **HL-LHC** (in production mode, now) and **Higgs Factory**
  - **Funding**: CIPROM/2024/69 ATENEA "Advanced Data Processing Technologies for Exploring New Physics in Future Particle Colliders"; PID2024- 156310NB-I00 "Upgrade de los sistemas TileCal y Trigger de ATLAS, estudios de física y desarrollos para detectores en Futuros" *(+PID2021..., finalized)*
- WP3 – PicoCAL/LHCb
  - **Goals**: **HL-LHC** (LS4)
  - **Funding**: PID2022-139842NB-C22 "Retando la Física y la Tecnología con el Detector Mejorado LHCb del CERN – IFIC

MoU…

- ▷We have a readable draft that has been shared with Dirección/Gerencia and the VRI of CSIC.
- ▷No common funds.
- ▷CSIC may be signing as “Collaborating Institution”
  - The drd6 intends to not fill the Funding Agencies tables (at this point)
- ▷Still unclear that the CSIC would accept the “whereas a):”
  - The institutions listed in Annex 1 (the “Collaborating Institutions”) have proposed a programme of research and development on particle detection technologies in the area of XXXX (the “R&D Programme”) and, **with support of their Funding Agencies[1]** , have agreed to form the XXX DRD collaboration (“the Collaboration”);
- ▷footnote
  - *A Funding Agency may be a Collaborating Institution or a body acting on behalf of one or more Collaborating Institutions in the conclusion of the MoU.*

Thanks for your attention

Backup slides

9th March 2026

Very Rich Physics Programme → Challenging Detectors

Higgs Factory Programme

- At $\sqrt{s}$=240 and $\sqrt{s}$=365 GeV collect 2.6M HZ and 150k WW→ H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling (~4 σ) via loop diagrams
- Unique possibility: s-channel $e^+e^- \rightarrow$ H at 125 GeV

→

- **Momentum resolution $\sigma(p_T)/p_T \simeq 10^{-3}$ @ $p_T \sim 50$ GeV**
  - σ(p)/p limited by multiple scattering → minimise material
- **Jet σ(E)/E ≃ 3-4% in multijet events for Z/W/H separation**
- **Superior impact parameter resolution for b, c tagging**
- **Hadron PID for s tagging**

Precision EW and QCD Programme

- 6 × 10^{12} Z and 2 × 10^8 WW events
- × 500 improvement of statistical precision on EWPO: m_Z, Γ_Z, Γ_{inv}, $\sin^2\theta_W$, R_b, m_W, Γ_W, ...
- 2 × 10^8 tt events: m_{top}, Γ_{top}, EW couplings
- Indirect sensitivity to new physics up to tens of TeV

→

- **Absolute normalisation of luminosity to 10^{-4}**
- **Relative normalisation to $\lesssim 10^{-5}$ (e.g. Γ_{had}/Γ_ℓ)**
  - Acceptance definition to $\mathcal{O}$(10 μm)
- **Track angular resolution < 0.1 mrad**
- **Stability of B field to 10^{-6}**

Heavy Flavour Programme

- 10^{12} bb, cc, 2 × 10^{12} ττ (clean and boosted): 10 × Belle II
- CKM matrix, CP measurements
- rare decays, CLFV searches, lepton universality

→

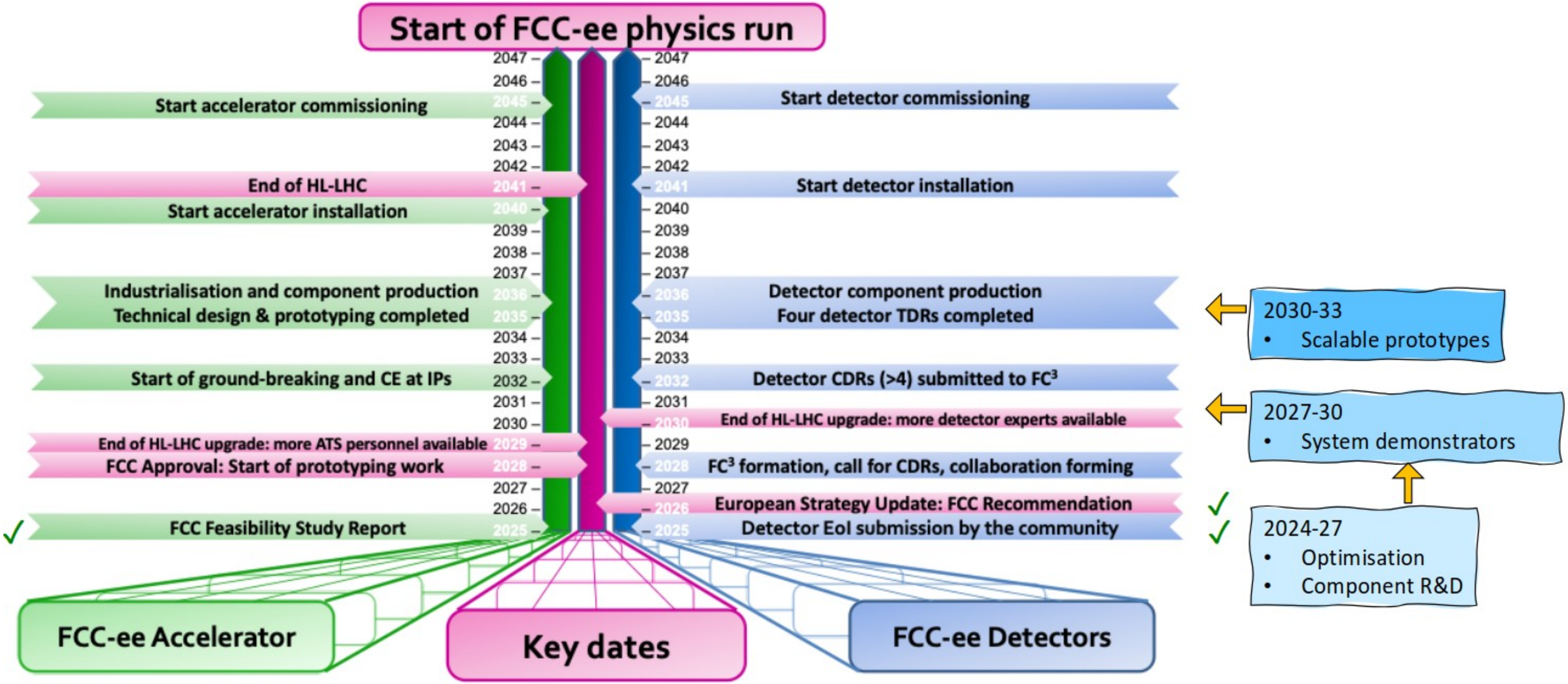
- **Superior impact parameter resolution**
- **Precise identification and measurement of secondary vertices**
- **ECAL resolution at few %/$\sqrt{E}$**
- **Excellent π^0/γ separation for τ decay-mode identification**
- **PID: K/π separation over wide p range** → dN/dx, RICH, timing

Feebly coupled particles Beyond SM

- Opportunity to directly observe new feebly interacting particles with masses below m_Z
- Axion-like particles, dark photons, Heavy Neutral Leptons
- Long-lifetime LLPs

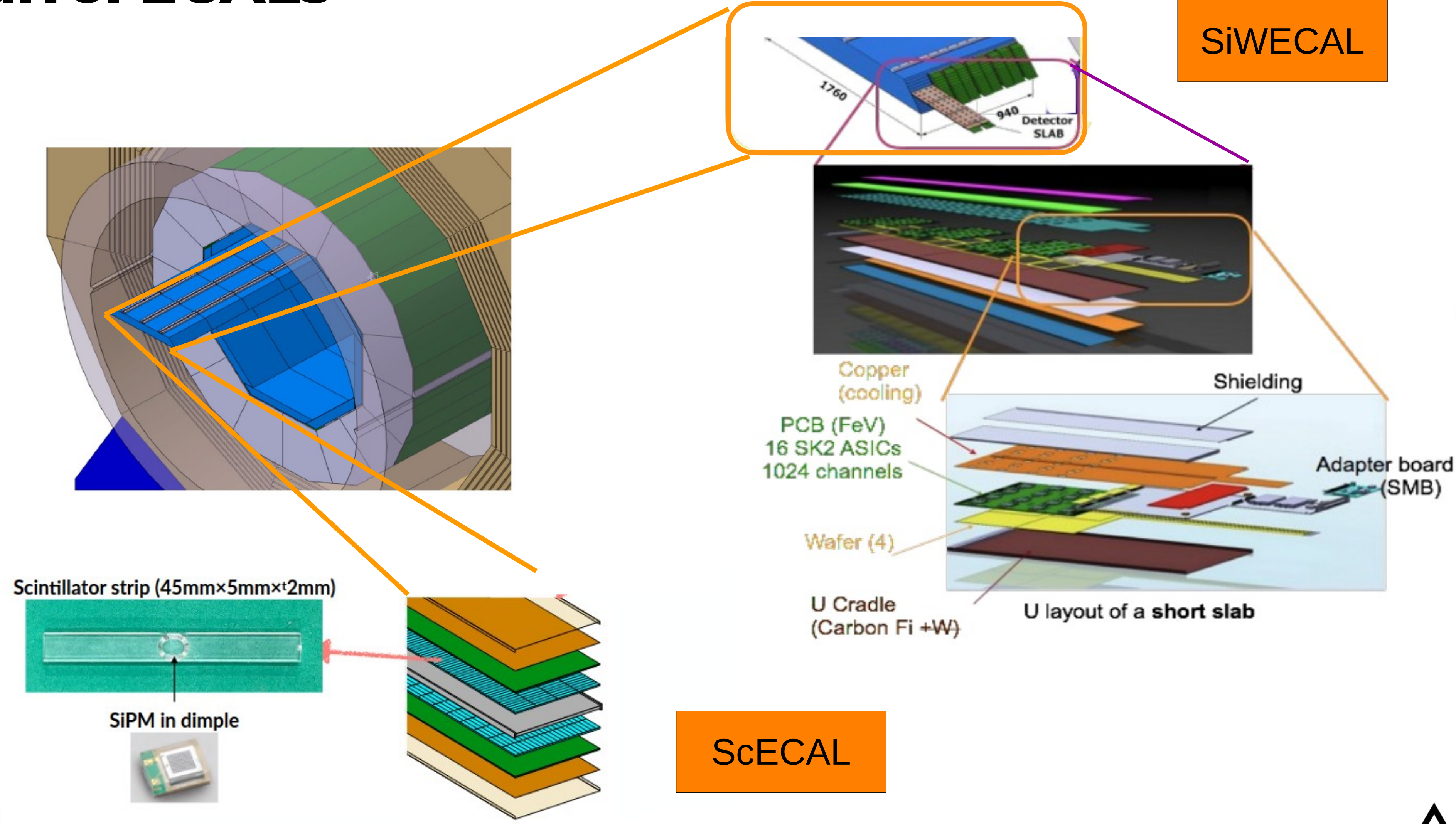
→

- **Sensitivity to (significantly) detached vertices (mm → m)**
  - tracking: more layers, "continous" tracking
  - calorimetry: granularity, tracking capabilities
- **Precise timing**
- **Hermeticity**



Start of FCC-ee physics run
2047
2046
2045
2044
2043
2042
2041
2040
2039
2038
2037
2036
2035
2034
2033
2032
2031
2030
2029
2028
2027
2026
2025
Start accelerator commissioning
End of HL-LHC
Start accelerator installation
Industrialisation and component production
Technical design & prototyping completed
Start of ground-breaking and CE at IPs
End of HL-LHC upgrade: more ATS personnel available
FCC Approval: Start of prototyping work
FCC Feasibility Study Report
Start detector commissioning
Start detector installation
Detector component production
Four detector TDRs completed
Detector CDRs (>4) submitted to FC³
End of HL-LHC upgrade: more detector experts available
FC³ formation, call for CDRs, collaboration forming
European Strategy Update: FCC Recommendation
Detector EoI submission by the community
FCC-ee Accelerator
Key dates
FCC-ee Detectors
2030-33
• Scalable prototypes
2027-30
• System demonstrators
2024-27
• Optimisation
• Component R&D

Barrel ECALs

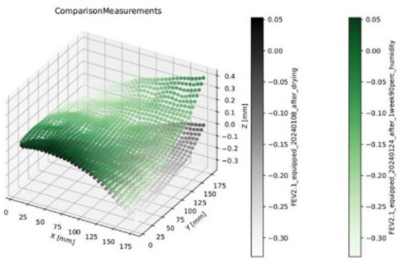


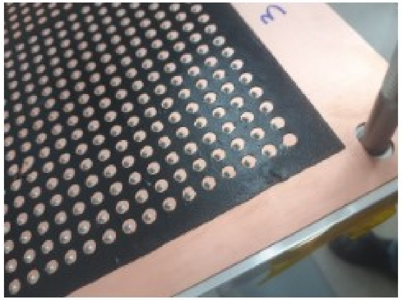
SiWECAL

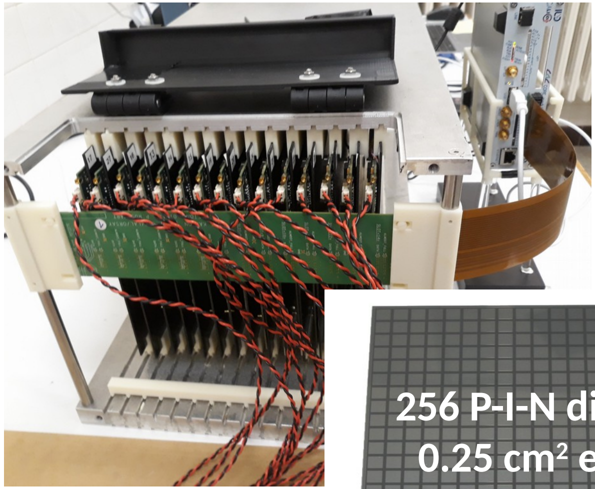
ScECAL

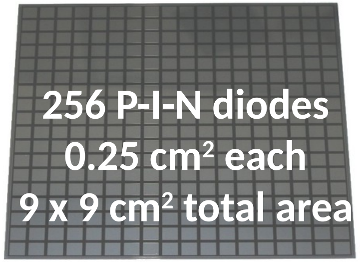
SiW-ECAL

SiW-ECAL (<2020)
- **15 layers 18×18 cm²**
- 0.5×0.5 cm² Si cells
- 2.8+5.6 mm W (21 X_0)
- 100 kg, 0.4×0.4×80 cm³
- **15k channels**
- **Sensor delamination issues**









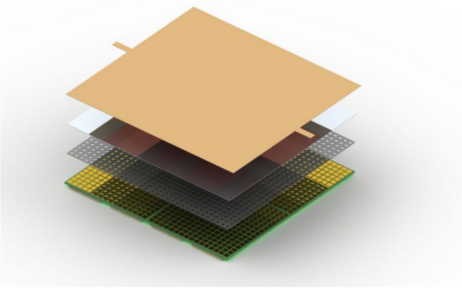
EUDET layout

Prototype from Hamamatsu

SiW-ECAL (ongoing)
- Goal 15 layers 18×18 cm²
- **New PCB generation & ASICs**
- **R&D on optmized hybridization**

- **Ongoing studies on requirements for Circular Colliders:**
  - - high fluxes
  - - cooling

- **5d calorimetry**



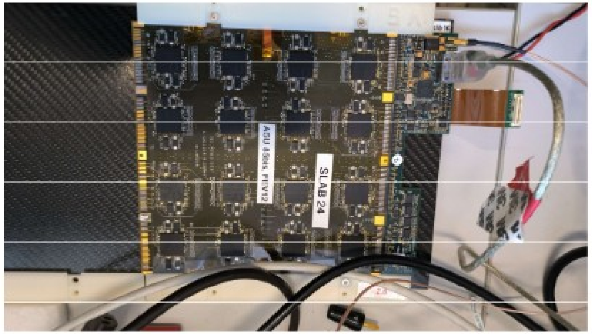
SiW-ECAL beam test at DESY (2025)

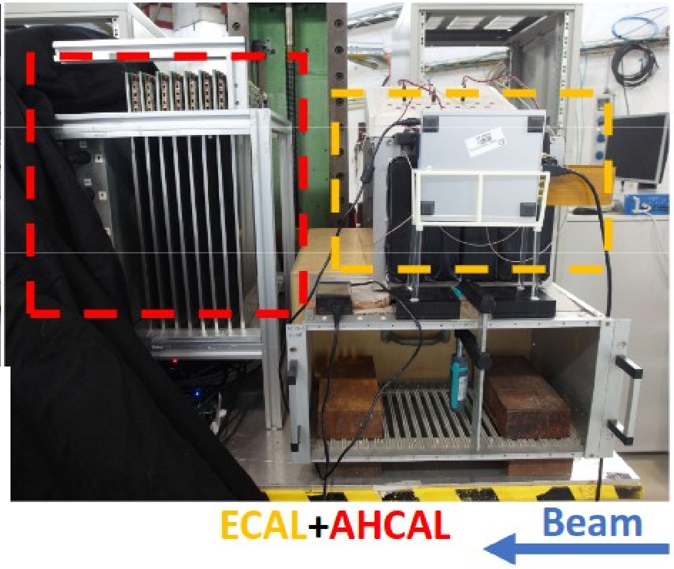
IFIC

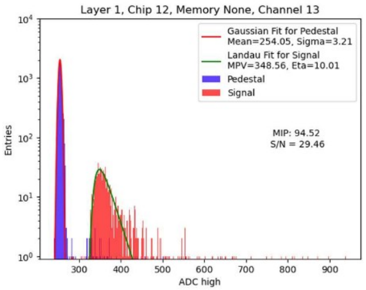
- ▷ **3 layers** (1-chip on board, 2 **new FEV2.1 boards** optimized for power-pulsing)
  - **New hybridization** techniques → developped by CNRS/IFIC
  - 32x32 cells of 5.5 x 5.5mm²
- ▷ Two weeks of data taking
  - **ECAL** standalone MIP calibration (and TDC calibration)
  - **ECAL+HCAL** → common data taking using AIDA TLU + EUDAQ

June 2026 – TB with 15 Layers
Up to 20-24X_0

During 2026
First integrations with CALOROC
(see C. De La Taille talk)

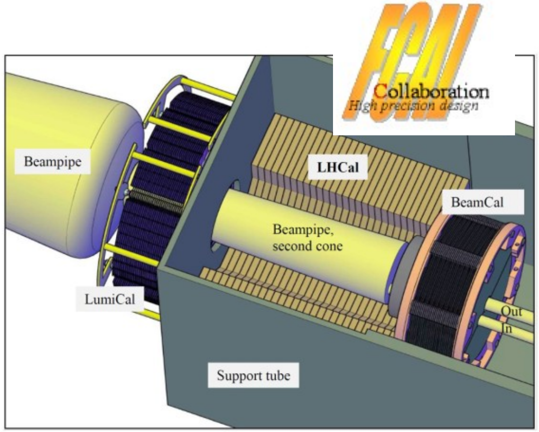






Forward Calorimetry (extreme compactness)

- ▷ LumiCal for precise luminosity measurement (Counting Bhabhas)
- ▷ BeamCal for fast luminosity measurement (using beamstrahlung)
- ▷ Technology choice: Si or GaAs/W sandwich calorimeters
- ▷ 1 X0 absorber thickness per layer, 20 (30) layers in ILC (CLIC)
  - Optimal geometries for FCC being studied



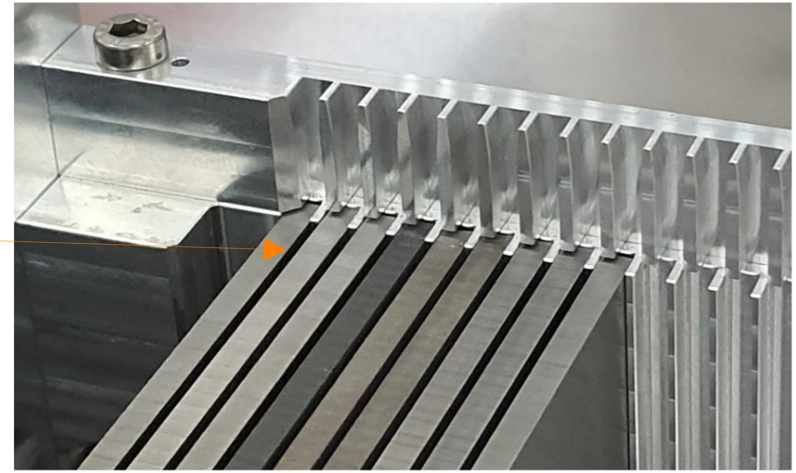
- ▷ Recent progress:
  - investigation of new GaAs sensors with integrated signal routing → similar signal size to silicon sensor (Eur.Phys.J.C 85 (2025) 6, 684)
  - **FLAMe and FLAXE ASICS** development and production (ongoing)

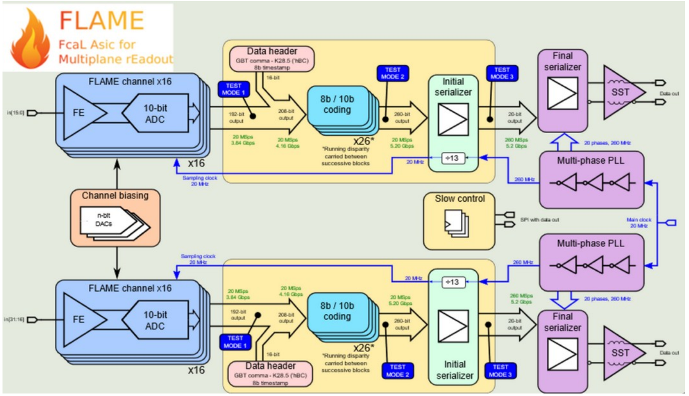
Production of a large scale prototype (adapted to LUXE)

AGH · University of Warsaw · Tel Aviv University · DESY · Institute of Space Science INFLPR Subsidiary · IFIC

Towards a full 20X0 prototype

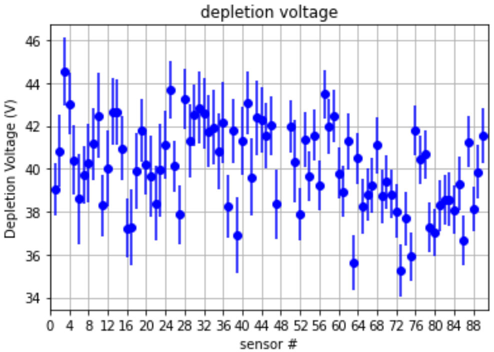
- ▷ Large sensors (9x9cm²) and **flexible PCBs (compact calo)**
- ▷ **Material budget, thickness:**
  - **Total bellow 1mm**
  - 200um CF + 320um sensor
  - ~500um for fanout + HV kapton + 3 layers of glue/Adhesive

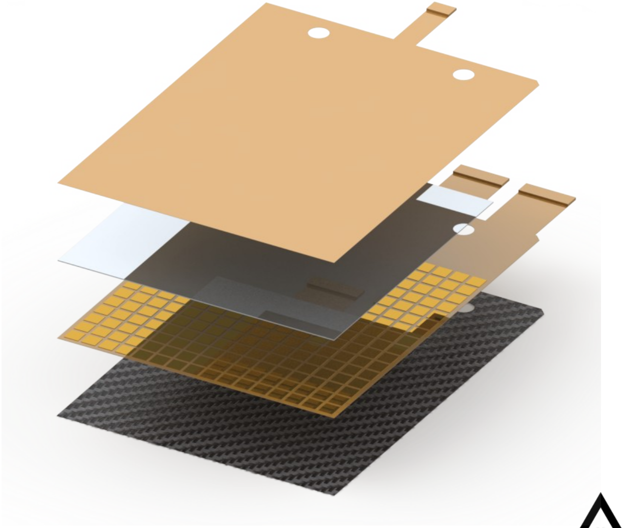




New readout with FLAXE for LUXE (based on FLAME)

- ▷ Same Si sensors as SiWECAL
  - 9x9cm², 256 pads

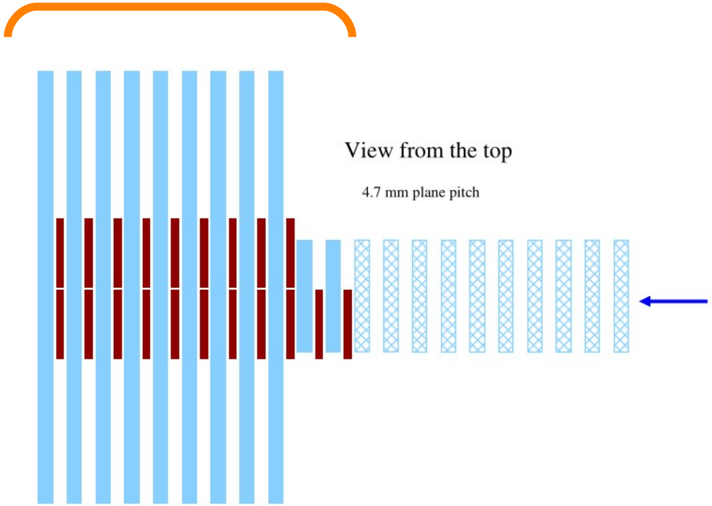




9th March 2026

Towards a full 20X0 prototype

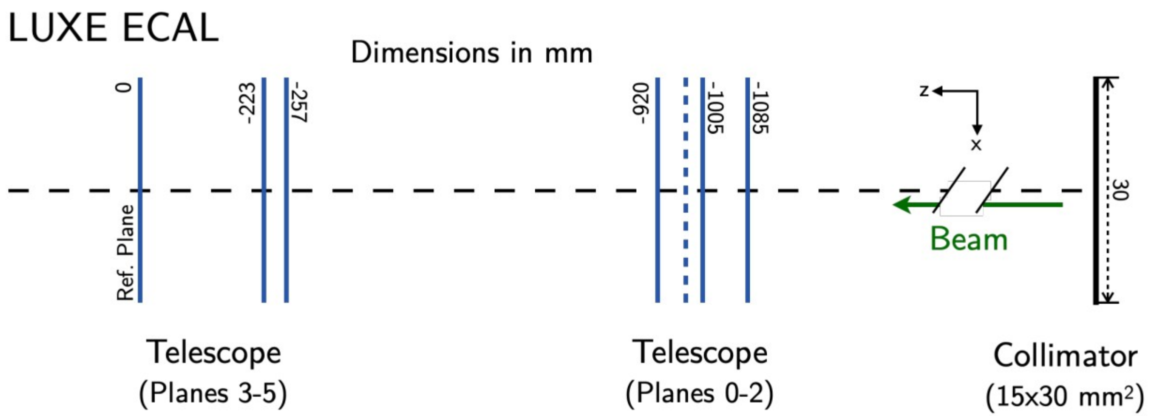
$10X_0 = 4.5$cm

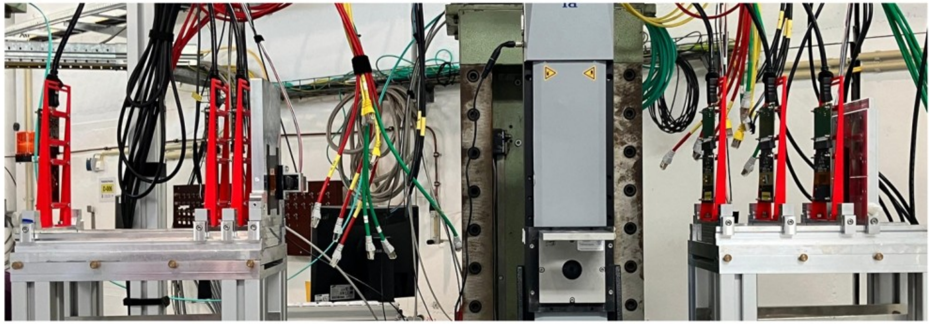


20 sensors in 11 planes

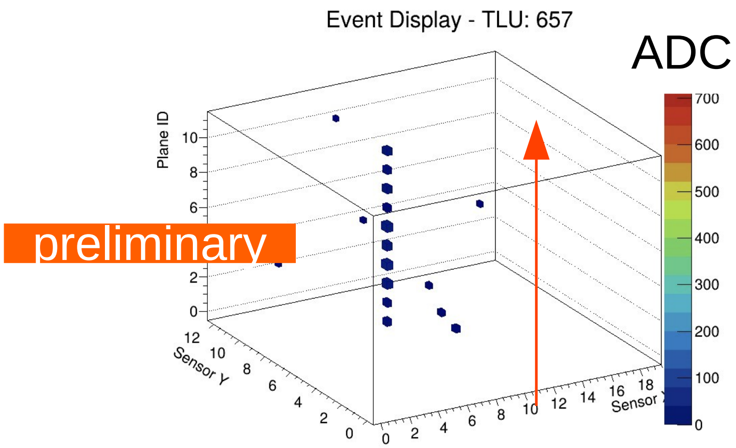
Two running configurations:

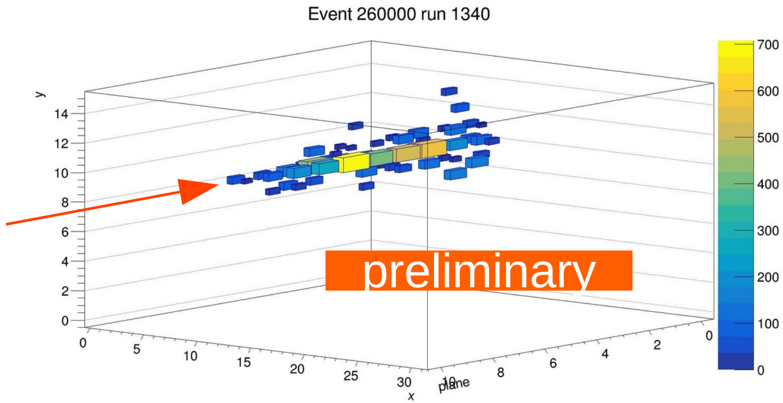
- without absorber (tracker mode)
- with 11 to 21 tungsten plates (calorimeter mode)



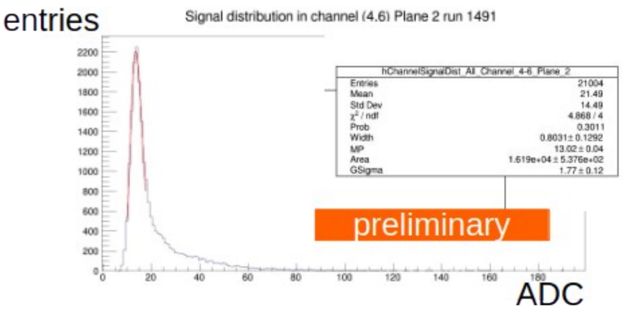


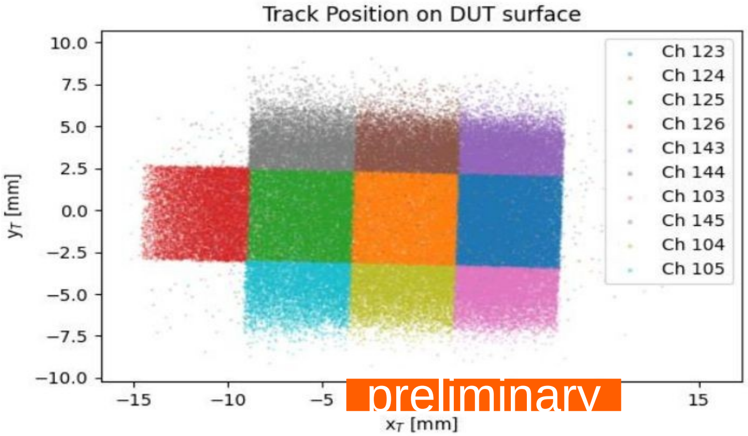
Analysing the data – starting effort





5 GeV showers





Hough Transform

IFIC – TileCAL for HL-LHC

2018 **TDR (Technical Design Report)**:
Tile Calorimeter Phase-II Upgrade TDR made public

2019 **PDR (Preliminary Design Review)** of the TileCal PPr Carrier Board
held in September (demonstrator installed at Point 1 in July for Run 3 data taking)

2020 **PDR (Preliminary Design Review)** of the TileCal CPM+TDAQi
held in March

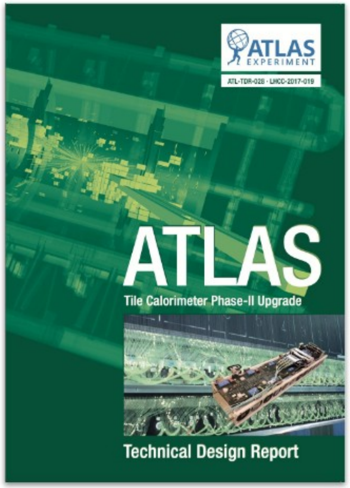
2021 Final design of the PPr module completed

2024 **FDR (Final Design Review)** of the TileCal PreProcessor
held in October, after that the PPr preproduction starts (4 PPr planned)

2026 **PRR (Production Readiness Review)**:
Carrier+CPM+TDAQ in Q1, after that the production of the remaining boards will start (32 PPr)

2027 Installation in ATLAS

2030 Run 4 start



ALLEGRO detector concept

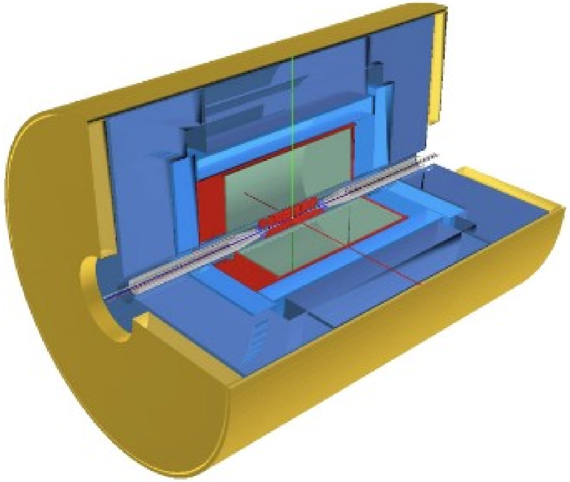
A **L**epton-**L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut: https://allegro.web.cern.ch

General-purpose detector for FCC:

- **2015:** Noble-liquid EM calorimeter for future experiments, part of the FCC-hh reference detector
- **2019:** CDR and input for ESPPU2020
- **2021:** Focus shifted to FCC-ee: noble-liquid ECAL concept adapted to lepton collider experiment
- **2022:** Detector concept proposed based on noble-liquid ECAL, reasonable choices for other sub-detectors
- **2023:** More groups joined, detector name and logo chosen, website created
- **2025:** EoI for ESPPU2025

Next steps:

- R&D on subdetectors
- TDR expected in the coming 5 years



ALLEGRO

16

ATENEA FCC calorimetry project (IFIC-CIEMAT)

- Title: **Advanced Data Processing Technologies for Exploring New Physics in Future Particle Colliders (ATENEA)**
  - Funded with 600k € during 2025-2029 by Generalitat Valenciana under the Prometeo program for excellence research groups (CIPROM/2024/69).
- Researchers (physicist / engineer):
  - **IFIC:** Arantxa Ruiz (PI), Ana Arranz, Iván Burriel, Fernando Carrió, David Hernández, Ximo Poveda, Alberto Valero, Juan Valls
  - **CIEMAT:** Cristina Fernández, Ignacio Redondo
- Context & Motivation:
  - Support **Future Circular Collider (FCC)** development.
  - Contribute to **ECFA Detector R&D Roadmap** in **DRD6** (Calorimetry) and **DRD7** (Electronics)
- **Main goals of the project:**

Physics case studies for FCC-ee & FCC-hh	**Develop advanced calorimeter components:** Multi-channel SiPMs / MPPCs, Radiation-hard readout/control electronics.	**Innovate DAQ systems** for massive data rates	**Real-time signal processing** with **NNs on FPGAs**	**Cross-disciplinary technology transfer** (electronics, computing, photodetectors)

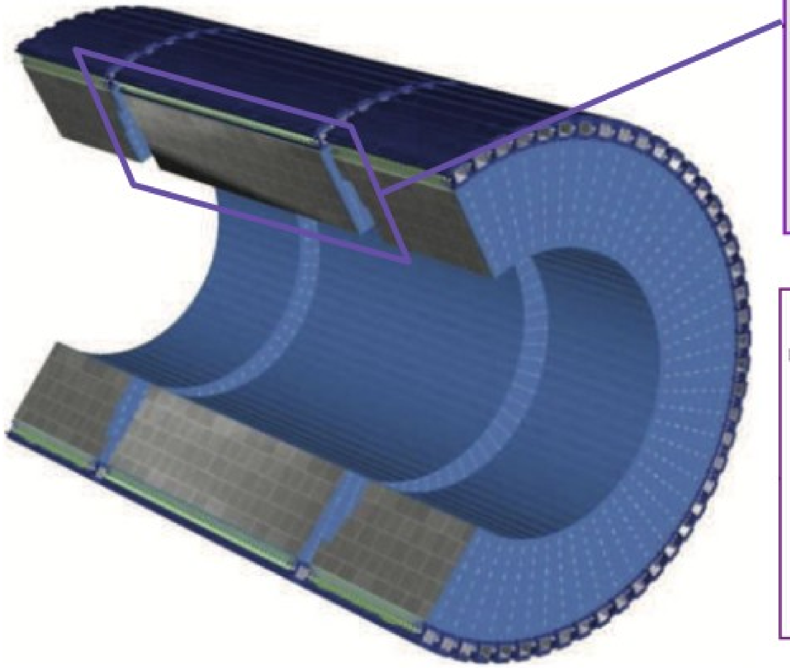
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

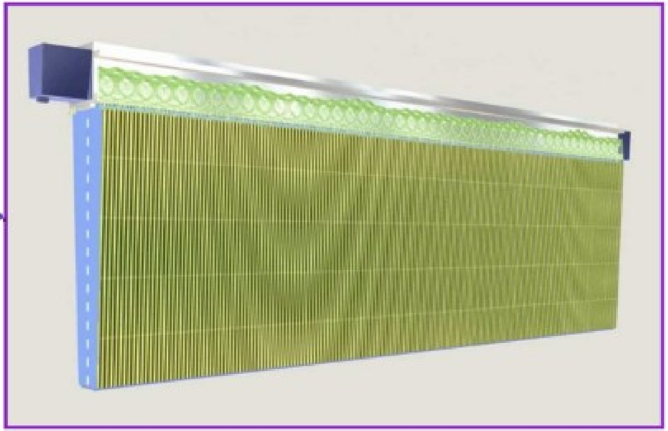
1

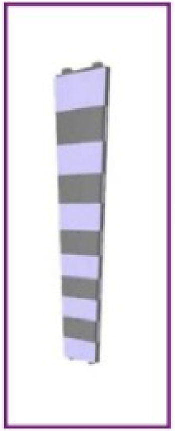
ATLAS Hadronic Tile Calorimeter (TileCal)

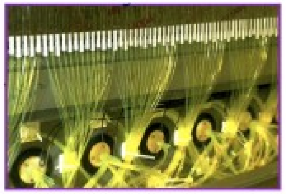
Tile Calorimeter

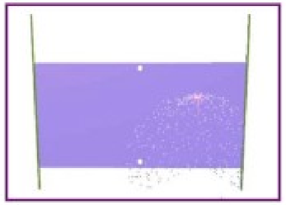
- Central hadronic calorimeter ($|\eta| < 1.72$)
- Steel and plastic scintillating tiles
- ~10.000 channels

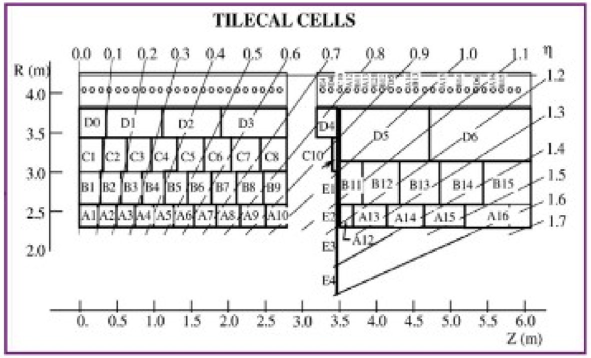


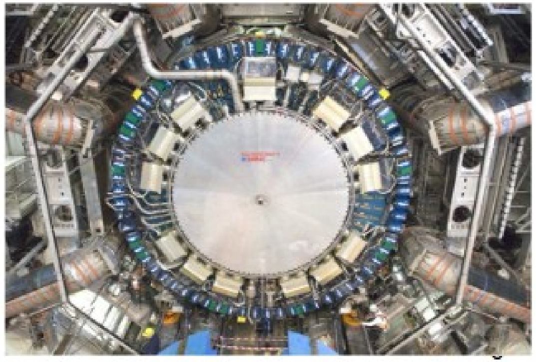




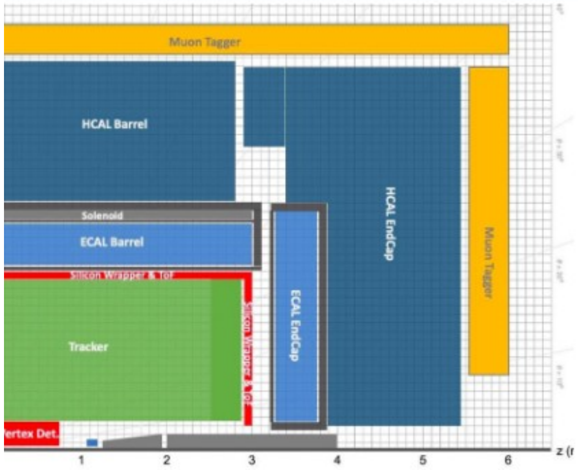








Allegro Concept



Vertex Detector

Tracking

Silicon Wrapper + ToF

High Granularity ECAL

- Excellent resolution, linearity, stability
- Optimised for particle flow
- Noble-liquid as active material

Solenoid B=2T (study option to go B>2T for c.o.m. energies > Z-pole), sharing cryostat with ECAL, between ECAL and HCAL

– Light solenoid coil ≈ 0.76 X_0

– Low-material cryostat < 0.1 X_0

High Granularity HCAL / Iron Yoke

Muon Tagger

strong noble-liquid ECAL team (20 institutes)

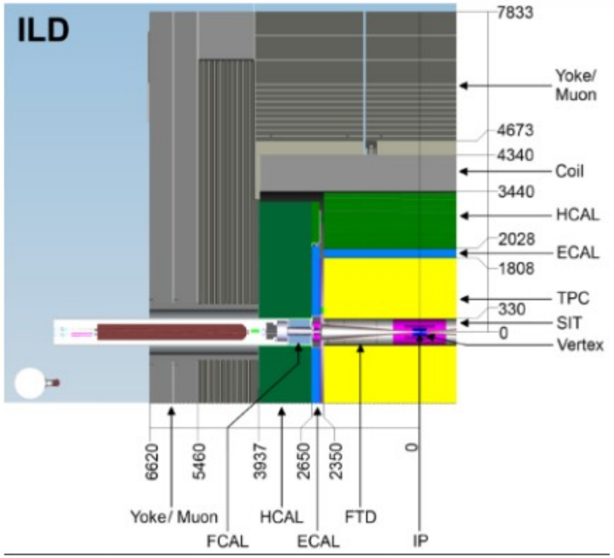
Martin Aleksa

From the beginning many different ideas/options → we should stay open for new ideas
Envelopes need to be optimised/adapted to chosen technologies → discussions in meetings of contact persons
At the moment one version was implemented into FCC SW, but all proposed sub-detectors should be implemented into FCC SW.

- In the coming years we should **further develop our ideas of detectors within the existing DRDs,** keeping the **physics requirements** in mind, **build prototype detectors** and **implement them into FCC SW** with **realistic performance**

- The **invitation to join ALLEGRO remains of course open** – there is plenty of space to contribute!
- We expect a **decision on FCC-ee in 2-3 years** from now. Will then enter the CDR and later TDR phase.
- **Many interesting challenges ahead of us! Come and join us!**

ILD Concept



ILD's design philosophy

jet energy measurement

- optimised for Particle Flow reconstruction
  - high granularity calorimetry

precision tracking in wide momentum range

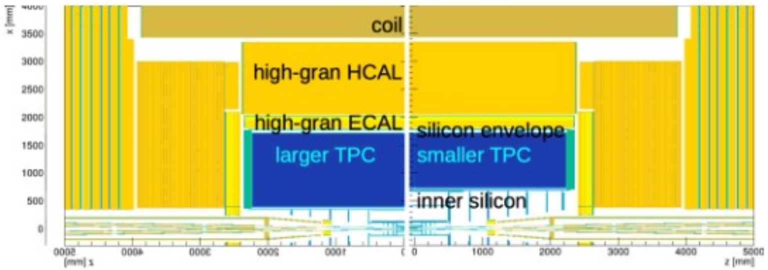
- hybrid tracking system : TPC + silicon

particle identification

- gaseous tracker + timing layer + high gran calo

Optimisation of ILD for FCCee + Studies of machine backgrounds

Can the TPC (and other subsystems) operate in these conditions ?
TPC with pixel readout for occupancy ?



Daniel Jeans

plans

FCCee-specific re-optimisation of subsystems, e.g.
- inner TPC radius
- silicon tracking layout
- calorimeter depth

Re-examination of subdetectors
- new technologies
- power/cooling/DAQ requirements

technical R&D needs

TPC
- robust against background environment:
  - occupancy, data rate
- methods to calibrate and correct distortions

Silicon trackers
- low mass support, cooling, readout infrastructure
- some with ~10 ps timing

High-granular calorimeters
- with infrastructure estimates

Detector solenoid

Invitation: ILD welcomes new contributors

to work with us on interesting open questions and tasks:

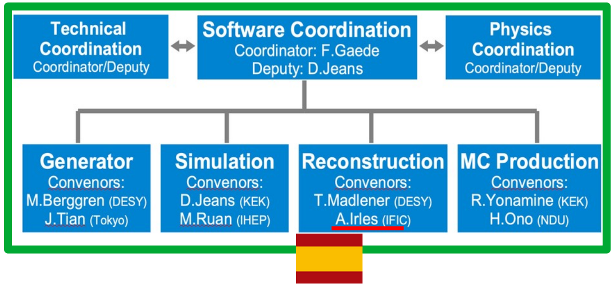
- propose & incorporate new detector technologies
- optimise the overall detector
- software tools, event reconstruction, physics studies
- (re)start engineering and integration studies

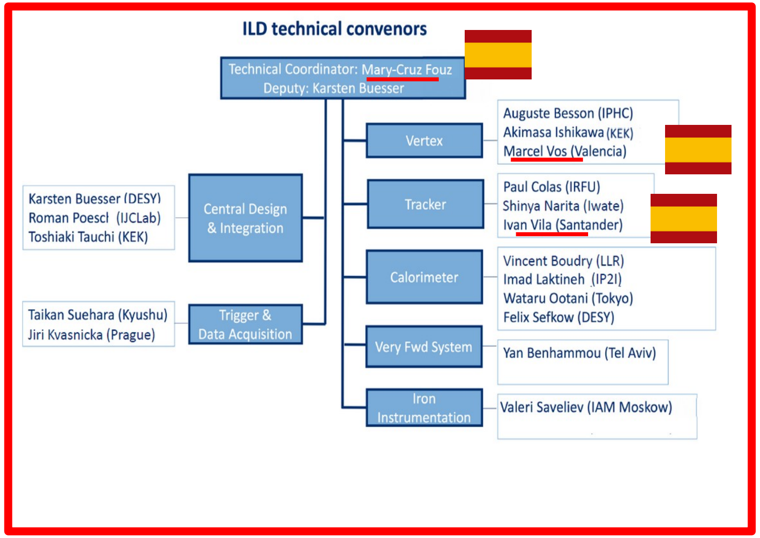
etc etc

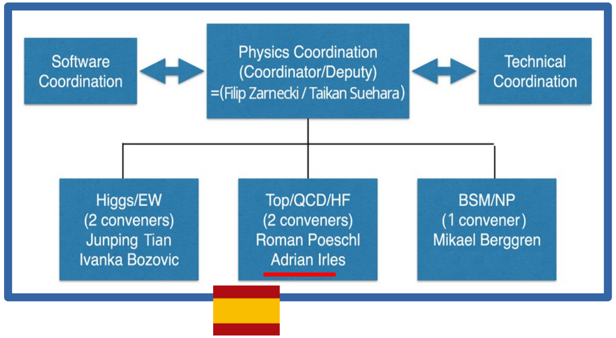
International Large Detector - Spain

- **6 spanish institutes, +30 members**
- CIEMAT – 5 members
  - Contact: MC. Fouz
- IFCA – 7 members
  - Contact A. Ruiz
- **IFIC +9 members**
  - Contact: A. Irles
- IMB-CNM – 2 members
  - Contact G. Pellegrini
- ITA – 6 members
  - Contact F. Arteche
- UB – 4 members
  - Contact A. Diequez

Spokesperson: Ties Behnke (DESY)
Institute Assembly Chair: Adrián Irles (IFIC)

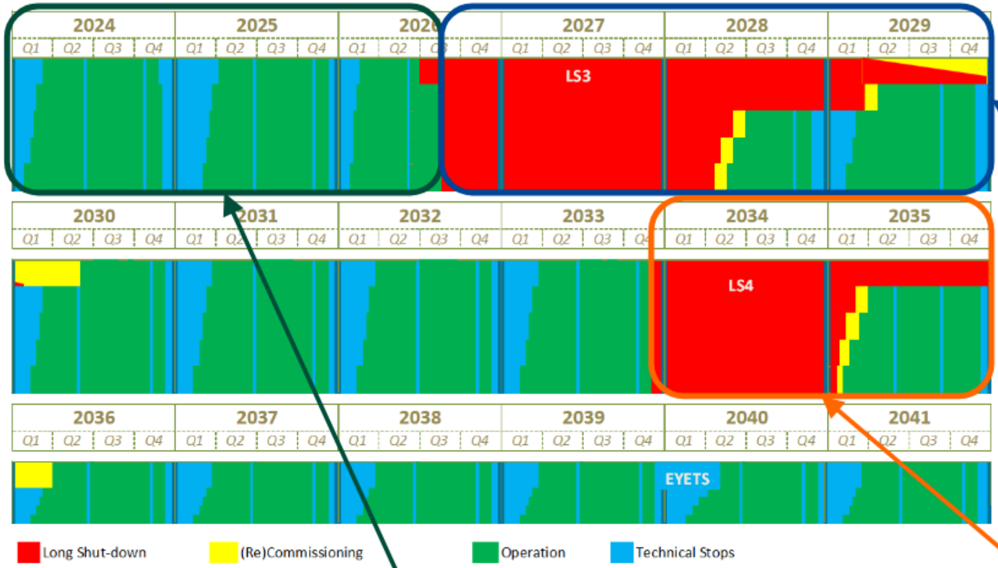






ESPPU2026 input: "The ILD Detector: A Versatile Detector for an Electron-Positron Collider at Energies up to 1 TeV"
https://arxiv.org/pdf/2506.06030
EOI FCC Detector Concept "Expression of Interest by the ILD concept groupfor an experiment at FCC-ee"

LHCb ECAL upgrade strategy



LS3 enhancement in 2026-2029:

- Introduce single-section rad. tolerant SpaCal (2x2 and 3x3 cm^2 cells) in inner regions and rebuilt ECAL in rhombic shape to improve performance at L = 2(4) x 10^{33} $cm^{-2}s^{-1}$
- Produce 110 FEBs almost identical to the Run 3 FEBs, using the Run 3 ICECAL ASIC and without time measurement

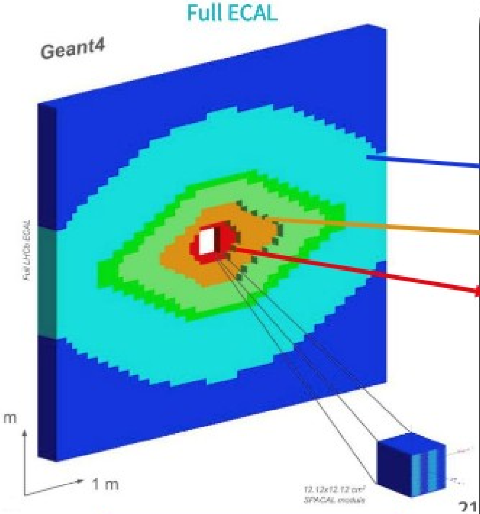
LS4 Upgrade II in 2034/2035:

- Introduce double-section radiation hard SpaCal (1.5x1.5 & 3x3 cm^2 cells) and improve timing of Shashlik modules for a luminosity of up to L = 1.5 x 10^{34} $cm^{-2}s^{-1}$
- 30208 channels (24 crates in total)
  - New FEB developed for all channels, with 64 channels per board: 470 FEBs
  - With final versions of ICECAL65 and SPIDER ASICs

Run 3 in 2022-2026:

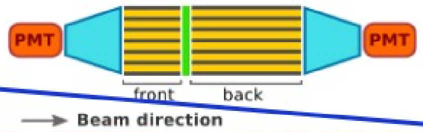
- Run with unmodified ECAL Shashlik modules at L = 2 x 10^{33} $cm^{-2}s^{-1}$
- Upgrade I 40 MHz readout (ICECAL)

PicoCal



Middle
$1.0 \times 10^{34}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
<u>PicoCal</u>
40 SpaCal-W
408 SpaCal-Pb
2864 Shashlik
double R/O
30,976 channels

SPACAL



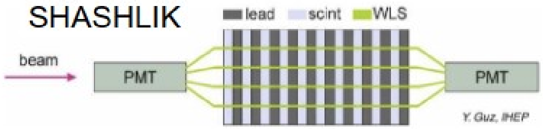
SPACAL-W

- W absorber, crystal fibers (GAGG, gadolinium aluminum gallium garnet)
- Large tolerance to radiations and small Molière radius
- Cell size 1.5x1.5 cm^2

SPACAL-Pb

- Pb absorber, polystyrene fibres
- Cell sizes
  - 3x3 cm^2
  - 4x4 cm^2

SHASHLIK



SPACAL-Pb

- Pb absorber, scintillator, YS4 fibres
- Current modules: outer region
- Cell sizes
  - 4x4 cm^2
  - 6x6 cm^2
  - 12x12 cm^2

Context: comparing FCC-ee vs HL-LHC

Compare triggered HL-LHC (ATLAS/CMS) vs FCC-ee T/DAQ variants
- Assume a single HL-LHC event is 4 MB, and a single FCC-ee event is 0.2 MB
- Assume the full FCC-ee physics rate at the Z pole is 200 kHz

	Raw input		—Trigger→ Filter input		—Filter→ Storage input	
HL-LHC	40 MHz	160 TB/s	1 MHz	4 TB/s	10 kHz	40 GB/s
FCC-ee	50 MHz	10 TB/s	0.5 MHz	0.1 TB/s	200 kHz	40 GB/s
	Streaming, with filter		50 MHz	10 TB/s	500 kHz	100 GB/s
			Streaming, no filter		50 MHz	10 TB/s

DAQ is capable of FCC-ee streaming readout: compatible with triggered HL-LHC
- However, streaming no-filter readout straight to disk may take too much space

The precision demands of the FCC-ee

FCC-ee physics case demands exqusite precision of the trigger system, if used
- Trigger efficiency uncertainty must be negligible compared to luminosity
- Any trigger bias between event types must be controlled to 1 part in 10^6
- These constraints motivate a streaming readout

M. Dam

HL-LHC DAQ hardware is perfectly capable of FCC-ee streaming readout
- However, this comes with a lot of associated material and power
- DAQ hardware for streaming readout may therefore degrade physics potential

Very preliminary assumptions on data size
Occupancy levels
(specially in the inner and forward tracking systems)